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Abstract: OBJECTIVE The aim of this systematic review and meta-analysis was to evaluate the effect of surface conditioning methods on the bond strength of industrial indirect composite blocks (ICs). METHODS Based on the PICOS strategy, the Medline via PubMed, Embase and Web of Science (ISI - Web of Knowledge) electronic databases were searched for peer-reviewed articles in both English and Chinese, with no publication year limit. In vitro studies evaluating the effects of surface conditioning on the bond strength of ICs were selected. The meta-analysis was conducted to calculate the mean difference between surface-conditioned ICs and unconditioned controls. Subgroup analysis was performed to evaluate the different surface conditioning methods, separately for polymer-infiltrated ceramic network (PICN) material and the ICs with dispersed fillers (ICDFs). Meta-analyses were performed with a random-effects model at a significance level of 0.05. RESULTS AND SIGNIFICANCE From 802 relevant studies, 25 were selected for full-text analysis. Nineteen studies were eligible for inclusion in this systematic review, whereas 9 studies were included in the meta-analysis. A manual search of the principal periodicals specific to the area resulted in no additional articles. The meta-analysis indicated a significant difference in bond strength between the surface-conditioned ICs and controls under both non-aged and aged conditions. The combination of mechanical and chemical conditioning yielded the highest bond strength of ICs. This meta-analysis suggests that chemical etching followed by a universal primer and alumina air abrasion followed by a silane coupling agent could be considered the best strategy for optimizing the bond strength of PICN materials and ICDFs under aged conditions, respectively.

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Bonding to industrial indirect composite blocks: a systematic review and meta-analysis

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KEY WORDS: Bonding; Composite resin; Dental; Indirect composite block

Declarations of interest: none

Abstract

Objectives. The aim of this systematic review and meta-analysis was to evaluate the effect of surface conditioning methods on the bond strength of industrial indirect composite blocks (ICs).

Sources. Based on the PICOS strategy, the MEDLINE via PubMed, Embase and Web of Science (ISI – Web of Knowledge) electronic databases were searched for peer-reviewed articles in both English and Chinese, with no publication year limit.

Data. From 802 relevant studies, 25 were selected for full-text analysis. Nineteen studies were eligible for inclusion in this systematic review, whereas 9 studies were included in the meta-analysis. A manual search of the principal periodicals specific to the area resulted in no additional articles.

Study selection. *In vitro* studies evaluating the effects of surface conditioning on the bond strength of ICs were selected. The meta-analysis was conducted to calculate the mean difference between surface-conditioned ICs and unconditioned controls. Subgroup analysis was performed to evaluate the different surface conditioning methods, separately for polymer-infiltrated ceramic network (PICN) material and the ICs with dispersed fillers (ICDFs). Meta-analyses were performed with a random-effects model at a significance level of 0.05.

Conclusions. The meta-analysis indicated a significant difference in bond strength between the surface-conditioned ICs and controls under both non-aged and aged conditions. The combination of mechanical and chemical conditioning yielded the highest bond strength of ICs. This meta-analysis suggests that chemical etching followed by a universal primer and alumina air

abrasion followed by a silane coupling agent could be considered the best strategy for optimizing the bond strength of PICN materials and ICDFs under aged conditions, respectively.

1. Introduction

Over the past few years, nonmetallic (metal-free) computer-aided design/computer aided manufacturing (CAD/CAM) materials, including ceramics and composites, have been widely used in dentistry [1]. Given that both materials have unfavorable properties related to the longevity of the restoration, an ideal restorative material would need to exhibit the positive characteristics of ceramics and composites and to overcome their disadvantages [2, 3]. Industrial indirect composite blocks (ICs) have therefore been fabricated under high temperature (HT) and/or high pressure (HP) and introduced as alternatives to the conventional ceramics and composites [1, 3]. Currently, two types of ICs are available in dentistry: polymer-infiltrated ceramic network (PICN) materials (e.g., Vita Enamic) and ICs with dispersed fillers (ICDFs, e.g., GC Cerasmart, 3M Lava Ultimate Restorative, and Shofu Block HC) [3-5]. PICN materials are characterized by a porous feldspar ceramic network that is infiltrated by a polymer, whereas ICDFs consist of a polymeric matrix reinforced by either nano (e.g., 3M Lava Ultimate Restorative) or nanohybrid (e.g., GC Cerasmart and Shofu Block HC) ceramic fillers [6]. As a PICN material, Vita Enamic is composed of a porous feldspathic ceramic (86 wt%) infiltrated with a polymer (14 wt%). For ICDFs, 3M Lava Ultimate Restorative contains silica and zirconia nanoparticles (80 wt%) embedded in a resin matrix (20 wt%), while GC Cerasmart contains silica and barium glass nanoparticles (71 wt%) in a resin matrix (29 wt%). Shofu Block HC contains silica and zirconium silicate (61 wt%) in a resin matrix (39 wt%) [7]. ICs have excellent flexural strength and internal discrepancy, even compared with the lithium disilicate glass-ceramic [6, 7]. ICs have an elasticity modulus closer to that of dentin and the property of absorbing masticatory forces, which can be particularly valuable for implant-supported restorations [3]. Additionally, ICs may be more easily fabricated and repaired than ceramics [8]. Although no clinical studies have been published, a full-mouth rehabilitation using PICN materials in severe eroded dentition remained intact at the 1-year follow-up in a case report [9]. Laboratory studies using clinical simulations have also shown promising results for ICs [10, 11]. A 5-year chewing simulation demonstrated that none of the PICN crowns (Vita Enamic) failed, while 6 lithium disilicate glass-ceramic crowns (IPS e.max CAD) had minor cracking, and 12 feldspar ceramic restorations (Vita Mark II) revealed significant crack failures [12].

A reliable bond between the restorative material and luting agent is a critical factor that affects the long-term success of restorations [13]. Since ICs exhibited relatively inferior mechanical properties compared with those of contemporary ceramics, adhesive bonding would be essential to achieve a higher fracture strength, increase retention, improve marginal adaption, and prevent the microleakage of restorations [3]. Moreover, the intraoral repair of chipped restoration requires a sufficient bond strength for long-term success [14, 15]. To obtain a higher volume fraction filler and higher conversion rate, ICs have been fabricated using HT (>100°C) and/or HP polymerization (>150 MPa) [3]. The industrial fabrication significantly improves the mechanical properties of the ICs [1, 16]. However, the high degree of conversion and the specific microstructure makes the bonding between ICs and composite cements more challenging, particularly with regard to their indications as adhesive restorations [3, 17, 18].

Recently, various surface conditioning methods to facilitate mechanical and chemical retention have been proposed to improve the bonding of ICs, including chemical etching (hydrofluoric acid and phosphoric acid), [19-22] alumina air abrasion, [19, 20, 22-24] tribochemical silica coating [19, 22], silane application [21-23], and universal adhesive/primer application [2, 19, 25]. Although surface conditioning has proven essential to promoting the bond strength of the ICs, no consensus has been achieved regarding the optimum surface conditioning methods. Moreover, the manufacturer (3M) recently withdrew the crown indication for Lava Ultimate Restorative because of a reportedly high debonding rate [3]. These facts highlight the importance of systematically collecting and analyzing bond strength data from the current literature. Bonding to ICs was reviewed by Spitznagel et al. [13, 26] in 2014 and 2016 and by Facenda et al. [27] in 2018. However, bonding to ICs has not been systematically reviewed, and no meta-analysis has been performed. Therefore, the aim of this study was to perform a systematic review and meta-analysis of in vitro studies investigating the bond strength of surface-conditioned ICs to composite cements. This meta-analysis was designed to test the null hypothesis that surface conditioning is not effective in promoting the bond strength of ICs fabricated under HT and/or HP.

2. Materials and Methods

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [28]. The present systematic review was conducted in an attempt to answer the following question: Do surface conditioning methods used for ICs increase their bond strength?

2.1. Information sources

A systematic electronic literature search was conducted in MEDLINE via PubMed, Embase, and Web of Science (ISI – Web of Knowledge). To complement the searches performed, manual searches were conducted in the following principal periodicals specific to the area: Journal of Dental Research, Dental Materials, Journal of Dentistry, Operative Dentistry, Clinical Oral Investigations, Journal of Prosthetic Dentistry, Journal of Oral Rehabilitation, International Journal of Prosthodontics, Journal of Prosthodontic Research, Dental Materials Journal, Journal of Prosthodontics, Journal of Adhesive Dentistry, and Zhonghua Kou Qiang Yi Xue Za Zhi (Journal published in Chinese). The search included peer-reviewed publications in English and Chinese languages and with no publication year limit. The last search was executed on December 20, 2018.

2.2. Search strategy

The PICOS questions were defined as follows: P-population: ICs bonded with composite cement; I-intervention: ICs received surface conditioning before bonding; C-control: specimens did not receive surface conditioning before bonding; O-outcome: whether surface conditioning methods improve the bond strength of the ICs was evaluated; S-study designs: the studies were *in vitro* studies.

The following MeSH terms, search terms, and their combinations were used in the PubMed search: ((("dental bonding"[MeSH Terms] OR resin bonding OR bond strength OR adhesion))) AND (resin-ceramic OR ceramic/polymer material OR polymer-infiltrated ceramic OR hybrid ceramic OR resin nano ceramic OR polymer-infiltrated-ceramic-network material OR CAD/CAM composite).

The following terms were used in the Embase search: ('dental bonding'/exp OR 'bond strength'/exp OR 'resin bonding') AND ('resin-ceramic' OR 'ceramic/polymer material' OR 'polymer-infiltrated ceramic' OR 'hybrid ceramic' OR 'resin nanoceramic' OR 'polymer-infiltrated-ceramic-network material') NOT [medline]/lim AND [embase]/lim.

The following terms were used in the Web of Science search: ("dental bonding" OR "resin bonding" OR "bond strength" OR adhesion) AND ("resin-ceramic" OR "ceramic/polymer material" OR "polymer-infiltrated ceramic" OR "hybrid ceramic" OR "resin nanoceramic" OR "polymer-infiltrated-ceramic-network material" OR "CAD/CAM composite").

2.3. Study selection and eligibility criteria

To minimize the potential for reviewer bias, two reviewers (H.Y. and M.O.) independently conducted electronic literature searches and performed the study selection. The level of agreement between the reviewers was determined by the Cohen K test, assuming K=0.61 to be an acceptable agreement score. Any disagreement was resolved by discussion or by consulting another reviewer (K.Y.).

Articles that met the following inclusion criteria were included in this systematic review: 1) studies that considered bonding to the ICs fabricated under HT and/or HP; 2) studies in which composite cements were used to bond the ICs; 3) studies using different surface conditioning methods prior to bonding; and 4) studies including a well-described bond strength test.

Articles meeting one or more of the following criteria were excluded: 1) *in vivo* or *in situ* studies; 2) studies testing materials other than composite cements such as brackets, ceramic, dentin, or enamel; 3) review, protocols, or clinical guidelines; and 4) studies testing repair bond strength.

For quantitative analyses (meta-analysis), studies lacking a control group or standard deviation values were excluded.

2.4. Data extraction and collection

Data were independently extracted by two reviewers (H.Y. and M.O.) using a format prepared on a Microsoft Excel Spreadsheet that had been trialed prior to use. Any disagreement was resolved by discussion or by consulting another reviewer (K.Y.).

The following data were collected from the included articles: demographic information (e.g., authors, journal, and title), ICs tested (type and commercial name), means and standard deviations of the bond strength, sample size, surface conditioning methods (e.g., mechanical and chemical), types of bond strength test (e.g., micro/macro and tensile/shear), adhesive system (e.g., commercial name and type of curing), shape of the tested interface and bonding area, aging methods, and load applied (mm/min). This systematic review and meta-analysis did not consider the mode of bond failure, since the definitions of failure mode varied widely, and not all the reviewed studies assessed this variable.

The authors of the studies were contacted in case of unpublished data. These studies were only included if the authors provided the missing information.

Surface conditioning methods were classified into 2 groups: mechanical conditioning and chemical conditioning. Mechanical conditionings were divided into 6 groups: 1) no mechanical conditioning (also included polishing with silicon carbide), 2) grinding with burs, 3) alumina air abrasion, 4) tribochemical silica coating, 5) laser irradiation, and 6) chemical etching. Chemical conditionings were divided into 4 groups: 1) no chemical conditioning, 2) silane, 3) universal adhesive/primer, and 4) silane-free universal adhesive.

All test groups were divided into 2 aging conditions: 1) aged condition applied to specimens either stored in water for longer than 2 months or subjected to thermocycling for more than 1,000 cycles [29]. Other aging protocols were excluded, since storage in 0.5% chloramine was applied in only 1 study [30]; 2) non-aged condition applied to specimens without being exposed to the abovementioned aging protocols.

2.5. Risk of bias assessment

The risk of bias assessment was based on an adapted protocol from previous systematic reviews [31, 32]. The assessment evaluated the description of the following parameters for the study's quality assessment: sample size calculation, adequate control group, surface conditioning methods clearly specified, materials used followed the manufacturers' instructions, tests executed by a single blinded operator, adequate statistical analysis, and randomization of specimens.

Each parameter reported by the included studies was recorded. Articles that included only one to three of these items were considered at high risk for bias; four or five items, at medium risk for bias; and six to eight items, at low risk for bias [32].

2.6. Data analyses

All the analyses were conducted using Review Manager software (version 5.3, Cochrane Collaboration, Oxford, UK). Statistical heterogeneity was detected using the I^2 statistic test. A random-effects model was used when high heterogeneity (I^2>50%) was detected. Otherwise, a fixed-effects model was used.

For the meta-analysis, data for surface-conditioned vs. control conditions were analyzed under both aging conditions. Subgroup analyses were also performed to assess different types of surface conditioning methods for the PICN material and the ICDFs. For studies that evaluated more than 1 type of ICs or more than 1 surface conditioning method, each type of material/conditioning method was considered independently.

3. Results

3.1. Study selection

Of 802 potentially relevant studies, 25 were selected for a full-text analysis, 19 were included in the systematic review, and 9 were considered in the meta-analysis (Fig. 1). The characteristics of the included studies are presented in Table 1. The included articles were published between 2014 and 2018.

3.2. Risks of bias

None of the included studies fulfilled all the requisites (Table 2). Of the 19 studies included in this systematic review, 5 (26.3%) presented a low risk of bias, 2 (10.15%) presented a high risk of bias, and the majority (12 studies, 63.2%) showed a medium risk of bias. None of the studies stated whether a single blinded operator executed the test or reported the sample size calculation.

3.3. Qualitative analysis

Of the 19 eligible studies, all were *in vitro* studies. The minimum number of specimens per group was 7, and the maximum specimen number per group was 100. Five types of ICs were identified in this systematic review. Of the studies included in the review, 13 studies evaluated Vita Enamic (Vita Zahnfabrik, Bad Säckingen, Germany) [2, 4, 19-22, 24, 30, 33-37], 11 evaluated Lava Ultimate Restorative (3M ESPE, St.Paul, USA) [4, 20, 22, 24, 25, 33, 35, 38-41], 4 studies evaluated GC Cerasmart (GC, Tokyo, Japan) [4, 23, 24, 30], 1 evaluated Mazic DUO (Vericom, Seoul, Korea) [40], and 1 evaluated Shofu Block HC (Shofu, Japan) [23].

For the mechanical conditioning methods, alumina air abrasion was used with different particle sizes, ranging from 27 μm to 110 μm, and different application pressures, ranging from 0.1 MPa to 0.5 MPa [20, 23, 24, 30, 33, 38, 40, 41]. Chemical etching was tested with different agents (phosphoric acid and hydrofluoric acid) and application times (5-300 s) [2, 4, 19, 21, 39]. Tribochemical silica coating was tested either alone or followed by silane application [34, 36, 39]. Furthermore, laser treatment (200 mJ, 10 Hz, 2W Er,Cr:YSGG) was used to condition Vita Enamic in 1 study [19].

For the chemical conditioning, silane and universal adhesives/primers were applied either alone or in combination with mechanical conditioning [2, 24, 25, 35, 37]. Light curing of the composite cements was adopted in most studies, whereas 1 study tested both light-curing and self-curing modes of composite cement [41].

In most studies, after the bonding procedure and prior to the bond strength tests, samples were stored in water at 37ºC for 1 d. Among the studies employing an aging treatment, thermocycling at 5ºC / 55ºC was the most frequently used method [4, 24, 33-35, 37, 38], whereas thermocycling at 4ºC/60ºC was used in 1 study [23]. The number of thermocycles ranged from 3,000 to 15,000. All the studies performed bond strength tests by means of a shear/tensile load at a crosshead speed of 0.5 or 1 mm/min. The shear bond test was the most commonly used test (10 studies), followed by the microtensile bond test (7 studies) and microshear test (2 studies), respectively.

3.4. Meta-analysis

Meta-analyses were performed based on 9 studies. The results were analyzed using the random-effects model because I^2 tests showed high heterogeneity. In general analysis of all surface conditioning methods in the eligible studies, bond strengths in the control groups (no surface conditioning) and surface-conditioned groups were compared under non-aged and aged conditions (Figs. 2 and 3). The analysis showed a significant difference in bond strength between the surfaced-conditioned ICs and the controls under non-aged ($P<0.00001$; mean difference [MD]: 17.48; 95% confidence interval [CI]: 15.84 to 19.13) and aged conditions ($P<0.00001$; MD: 8.11; 95% CI: 6.42 to 9.81), favoring surface conditioning. Moreover, surface conditioning exhibited different effects on the bond strength of the PICN material and ICDFs under the non-aged condition ($P<0.00001$).

A subgroup meta-analysis was further conducted considering different conditioning methods (mechanical, chemical, and combination) for the PICN material (Figs. 4 and 5) and the ICDFs (Figs. 6 and 7) under the non-aged and aged conditions. In general, the combination of mechanical and chemical conditioning methods yielded a significantly greater increase in the bond strength of the ICs than that when mechanical or chemical conditioning methods were applied alone.

For the PICN material, all the surface conditioning methods produced a significantly higher bond strength than that of the control under aged conditions. Chemical etching showed a significantly greater increase in the bond strength than did alumina air abrasion. Chemical etching followed by a universal primer provided the greatest increase in the bond strength of the PICN material ($P<0.00001$; MD: 12.28; 95% CI: 11.19 to 13.36).

Regarding ICDFs, no significant differences in the bond strength was found between the surface-conditioned group and the control when chemical etching or universal primer application was performed alone under aged conditions. Alumina air abrasion followed by silane application yielded the highest bond strength under aged conditions ($P<0.00001$; MD: 27.00; 95% CI: 24.32 to 29.68).

4. Discussion

This review accessed the effect of surface conditioning methods on the bond strength of ICs fabricated under HT and/or HP and can be considered the first systematic review and meta-analysis in this field. A broad search of publications in 2 major languages was performed with no publication date restrictions. Based on the existing data, the null hypothesis that surface conditioning is not effective in promoting the bonding of the ICs fabricated under HT and/or HP is therefore rejected. However, meta-analyses were executed on only restricted types of surface conditioning methods due to the limited number of available studies. Two types of ICs (PICN material and ICDFs) were analyzed in the subgroup meta-analyses independently when evaluating the bond strength results, since different behaviors could be exhibited depending on their composition.

In fact, various recommendations have been proposed by the manufacturers of the materials included in this systematic review. Mechanical conditioning followed by chemical conditioning is generally recommended by most manufacturers [42-44]. Interestingly, chemical conditioning alone (primer application) was the recommended treatment for one of the ICDFs (Shofu HC block) [45]. In general, the meta-analyses showed that the surface conditioning provided a positive effect on the bond strength of the ICs. The combination of mechanical and chemical conditioning yielded the highest bond strength under both aged and non-aged conditions.

Regarding the mechanical conditioning methods, alumina air abrasion and chemical etching using hydrofluoric acid on the ICs were the most commonly used. Chemical etching and alumina air abrasion have been shown to enhance the mechanical interlocking of composite cement and restorative materials by roughening the surface, increasing the surface energy and wettability [46, 47]. However, distinct differences were found in the optimum mechanical conditioning methods between the PICN material and ICDFs, indicating that the composition of the ICs should be considered to determine the surface conditioning methods. For the PICN material, chemical etching tended to provide a higher bond strength than did alumina air abrasion. With regard to the ICDFs, alumina air abrasion provided better results than did chemical etching. This finding is in accordance with previous studies [20, 22, 33] and with the manufacturers' instructions [42]. Indeed, with PICN material, the chemical etching procedure induces the dissolution of the glassy phase, while the polymer network remained unchanged [2, 3]. This action creates a honeycomb structure formed by the remaining polymer network, offering a high potential for micromechanical interlocking. Furthermore, the surface topographic changes in the PICN material due to chemical etching were found to be more evident than those due to alumina air abrasion, which is probably a consequence of the distinctly different compositions and microstructures of the 2 types of ICs [19]. Compared with the ICDFs, the PICN material has a greater amount of silica-based ceramic, which can be reacted with the hydrofluoric acid. Different particle sizes and application pressures were also tested for alumina air abrasion. However, direct comparisons of different parameters are hard to execute. Arao et al. [23] compared the effects of alumina air abrasion at 0.2 MPa and 0.4 MPa on the surface roughness of ICDFs (GC Cerasmart and Shofu HC Block). No significant differences were found in the surface roughness after alumina air abrasion at different application pressures. In the literature, the time of chemical etching using hydrofluoric acid ranged from 5 s to 300 s [2, 4, 19, 21, 39]. Rohr et al. [2] reported that the highest bond strengths of the ICs were obtained after chemical etching for 30-60 s. Notably, subsurface/surface damage due to the mechanical conditioning for a prolonged period of time might compromise the mechanical strength of the ICs [48]. Moreover, tribochemical silica coating was also tested for the PICN material and ICDFs and failed to provide better results than did chemical etching/alumina air abrasion, showing that micromechanical interlocking seems to play the most important role in adhesion [19, 22, 38]. Apart from those conventional mechanical conditioning methods, Barutcigil et al. [19] applied Er,Cr:YSGG laser treatment to the PICN material. A higher but nonsignificant difference was found in the surface roughness and the shear bond strength of laser-treated specimens than found in the controls.

When the chemical conditioning was performed alone, the elevated bond strength was significantly lower than the mechanical conditioning, which is in agreement with previous studies [13, 22, 23]. This finding highlights the notion that mechanical conditioning by increasing surface roughness and micromechanical interlocking contributes more to the bonding properties of the ICs than does chemical conditioning (e.g., silane coupling agent and universal primer) [2, 13]. Interestingly, universal primer was able to exert more positive effect on the bond strength of the ICs than did silane coupling agent. The silane coupling agents were proven to provide chemical bonds to silica-based ceramic [49]. The polymer phase of the ICs does not participate in any chemical bonds while silane coupling agents are applied alone [2, 21]. The universal adhesives/primer, which usually contains an acidic functional monomer (e.g., methacryloyloxydecyl dihydrogen phosphate (MDP)), a silane coupling agent, and/or a methacrylate monomer [4], are designed to promote the bonding of different dental substrates/materials. ICs contain two phases: an inorganic ceramic/glass phase and a polymer matrix [4]. The MDP monomer is proven to promote bonding of zirconia, alumina, and metals, which are the components of ICs [15]. Furthermore, bonding to the polymer might be achieved via acid groups of the copolymer and MDP in the universal adhesives/primer [2]. In this manner, the universal adhesive/primer may establish bonding to both the polymer and ceramic phases of ICs and provide better results than using silane coupling agents alone. When comparing the effect of chemical conditioning on the bond strength of the ICs under non-aged and aged conditions, the results indicated that the promoted adhesion due to chemical conditioning was degraded by aging. The mechanism may be that the chemical linkage (Si-O-Si) and/or coordinate bond established by functional monomer after chemical conditioning is susceptible to hydrolysis [50, 51].

The current findings indicated that the combination of two or more surface conditioning methods can improve the positive effect of each protocol, increasing the bond strength of the ICs. The present study showed that chemical etching followed by universal primer application provides the highest bond strength values for PICN materials, whereas the alumina air abrasion followed by silane application exhibits the best bonding performance for ICDFs, under aged conditions. This finding is consistent with those of the previous studies [2, 33, 37]. Chemical etching using hydrofluoric acid can dissolve the glass phase of ICs by reacting with silicon dioxide, while alumina air abrasion can increase the surface adherent area by roughening both phases of the ICs.

Both the abovementioned conditioning methods create the micromechanical retention/interlocking between the composite cements and the ICs and a larger reacting area for the following chemical conditioning. When evaluated alone, a higher bond strength of ICs was achieved by conditioning with universal primer. However, a higher bond strength of the ICDFs was recorded when the silane application was performed after the mechanical conditioning. This result is probably due to the synergetic effects of the conditioning methods. However, there are limited data available in the literature. Further investigations were needed to clarify this hypothesis. Moreover, in 1 recently published study, the highest bond strength to PICN material was achieved when silane was applied followed by the universal adhesive [2]. The higher bond strengths for a combined application of silane and universal adhesive probably indicates that the silane incorporated in the universal adhesive is insufficient in terms of chemical adhesion to a silicate ceramic surface [2, 25].

The risk of bias was found to be medium in 12 studies and, together with high heterogeneity, highlights the need for standardized methods for future investigations. The variety of tests used by researchers makes the data difficult to compare under different experimental conditions. Despite the lack of consensus regarding which test is the most appropriate, the shear bond test was the most frequent used methodology for measuring the bond strength between composite cements and ICs. Bond strength values obtained under aged conditions are likely to be a more reliable evidence of the actual long-term clinical performance. Thermocycling was performed in the majority of the included studies (12 out of 19), using different protocols with varying numbers of cycles (3000 to 15000 cycles) and temperatures (5/55ºC and 4/60ºC).

Temperature changes during the thermocycling process may amplify the coefficient of thermal expansion mismatch of the bonded materials, which generates mechanical stresses at the bonded interface, resulting in bond strength degradation [52]. Most of the studies stored samples in distilled water at 37ºC for 1 d prior to bond strength tests. However, some studies changed this protocol to 2 d [4, 33] or 2 weeks [38], or even different temperatures (e.g., 25ºC) [41]. Therefore, the high heterogeneity showed in the meta-analyses could be due to the varied experimental protocols, test materials, and sample size, etc. Although sensitivity analyses were conducted, no particular studies were responsible for generating heterogeneity. Moreover, the meta-analyses were not performed according to the composite cement types due to the wide variety of materials used and the limited available studies in the current literature.

Based on the present study, alumina air abrasion followed by silane application and chemical etching followed by universal primer application appears to provide the highest long-term bond strength of ICDFs and PICN material, respectively. However, notably, the number of test groups supporting these results was limited. Therefore, these results should be interpreted with caution before being applied to clinical situations. Further laboratory and clinical research is needed to confirm the long-term bond strength of surface-conditioned ICs and provide evidence-based recommendations for clinical practice.

5. Conclusions

Although the studies showed high heterogeneity, based on this meta-analysis, chemical etching followed by silane application and alumina air abrasion followed by universal adhesive application could be considered the best strategy for optimizing the bond strength of PICN material and ICDFs under aged conditions, respectively.

References

[1] Ruse ND, Sadoun MJ. Resin-composite blocks for dental CAD/CAM applications. J Dent Res 2014; 93: 1232-4. http://dx.doi.org/10.1177/0022034514553976.

[2] Rohr N, Flury A, Fischer J. Efficacy of a universal adhesive in the bond strength of composite cements to polymer-infiltrated ceramic. J Adhes Dent 2017; 19: 417-24. http://dx.doi.org/10.3290/j.jad.a39277.

[3] Mainjot AK, Dupont NM, Oudkerk JC, Dewael TY, Sadoun MJ. From artisanal to CAD-CAM blocks: state of the art of indirect composites. J Dent Res 2016; 95: 487-95. http://dx.doi.org/10.1177/0022034516634286.

[4] Cekic-Nagas I, Ergun G, Egilmez F, Vallittu PK, Lassila LV. Micro-shear bond strength of different resin cements to ceramic/glass-polymer CAD-CAM block materials. J Prosthodont Res 2016; 60: 265-73. http://dx.doi.org/10.1016/j.jpor.2016.02.003.

[5] Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dent Mater 2014; 30: 564-9. http://dx.doi.org/10.1016/j.dental.2014.02.019.

[6] Goujat A, Abouelleil H, Colon P, Jeannin C, Pradelle N, Seux D, et al. Mechanical properties and internal fit of 4 CAD-CAM block materials. J Prosthet Dent 2018; 119: 384-9. http://dx.doi.org/10.1016/j.prosdent.2017.03.001.

[7] Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015; 114: 587-93. http://dx.doi.org/10.1016/j.prosdent.2015.04.016.

[8] van Noort R. The future of dental devices is digital. Dent Mater 2012; 28: 3-12. http://dx.doi.org/10.1016/j.dental.2011.10.014.

[9] Dirxen C, Blunck U, Preissner S. Clinical performance of a new biomimetic double network material. Open Dent J 2013; 7: 118-22. http://dx.doi.org/10.2174/1874210620130904003.
[10] Denry I, Kelly JR. Emerging ceramic-based materials for dentistry. J Dent Res 2014; 93: 1235-42. http://dx.doi.org/10.1177/0022034514553627.
[11] Kelly JR, Rungruanganunt P, Hunter B, Vailati F. Development of a clinically validated bulk failure test for ceramic crowns. J Prosthet Dent 2010; 104: 228-38. http://dx.doi.org/10.1016/S0022-3913(10)60129-1.
[12] Swain MV, Coldea A, Bilkhair A, Guess PC. Interpenetrating network ceramic-resin composite dental restorative materials. Dent Mater 2016; 32: 34-42. http://dx.doi.org/10.1016/j.dental.2015.09.009.
[13] Spitznagel FA, Horvath SD, Guess PC, Blatz MB. Resin bond to indirect composite and new ceramic/polymer materials: a review of the literature. J Esthet Restor Dent 2014; 26: 382-93. http://dx.doi.org/10.1111/jerd.12100.
[14] Wiegand A, Stucki L, Hoffmann R, Attin T, Stawarczyk B. Repairability of CAD/CAM high-density PMMA- and composite-based polymers. Clin Oral Investig 2015; 19: 2007-13. http://dx.doi.org/10.1007/s00784-015-1411-x.
[15] Agingu C, Zhang C, Jiang N, Cheng H, Ozcan M, Yu H. Intraoral repair of chipped or fractured veneered zirconia crowns and fixed dental prosthesis: Clinical guidelines based on literature review. J Adhes Sci Technol 2018; 32: 1711-23. https://doi.org/10.1080/01694243.2018.1443639.
[16] Nguyen JF, Migonney V, Ruse ND, Sadoun M. Resin composite blocks via high-pressure high-temperature polymerization. Dent Mater 2012; 28: 529-34. http://dx.doi.org/10.1016/j.dental.2011.12.003.
[17] Kawaguchi A, Matsumoto M, Higashi M, Miura J, Minamino T, Kabetani T,

et al. Bonding effectiveness of self-adhesive and conventional-type adhesive resin cements to CAD/CAM resin blocks. Part 2: Effect of ultrasonic and acid cleaning. Dent Mater J 2016; 35: 29-36. http://dx.doi.org/10.4012/dmj.2015-235.

[18] Bahr N, Keul C, Edelhoff D, Eichberger M, Roos M, Gernet W, et al. Effect of different adhesives combined with two resin composite cements on shear bond strength to polymeric CAD/CAM materials. Dent Mater J 2013; 32: 492-501.

[19] Barutcigil K, Barutcigil C, Kul E, Ozarslan MM, Buyukkaplan US. Effect of different surface treatments on bond strength of resin cement to a CAD/CAM restorative material. J Prosthodont 2016. http://dx.doi.org/10.1111/jopr.12574.

[20] Elsaka SE. Bond strength of novel CAD/CAM restorative materials to self-adhesive resin cement: the effect of surface treatments. J Adhes Dent 2014; 16: 531-40. http://dx.doi.org/10.3290/j.jad.a33198.

[21] Schwenter J, Schmidli F, Weiger R, Fischer J. Adhesive bonding to polymer infiltrated ceramic. Dent Mater J 2016; 35: 796-802. http://dx.doi.org/10.4012/dmj.2015-271.

[22] Peumans M, Valjakova EB, De Munck J, Mishevska CB, Van Meerbeek B. Bonding effectiveness of luting composites to different CAD/CAM materials. J Adhes Dent 2016; 18: 289-302. http://dx.doi.org/10.3290/j.jad.a36155.

[23] Nobuaki A, Keiichi Y, Takashi S. Effects of air abrasion with alumina or glass beads on surface characteristics of CAD/CAM composite materials and the bond strength of resin cements. J Appl Oral Sci 2015; 23: 629-36. http://dx.doi.org/10.1590/1678-775720150261.

[24] Gungor MB, Nemli SK, Bal BT, Unver S, Dogan A. Effect of surface treatments on shear bond strength of resin composite bonded to CAD/CAM

resin-ceramic hybrid materials. J Adv Prosthodont 2016; 8: 259-66. http://dx.doi.org/10.4047/jap.2016.8.4.259.

[25] Yoshihara K, Nagaoka N, Sonoda A, Maruo Y, Makita Y, Okihara T, et al. Effectiveness and stability of silane coupling agent incorporated in 'universal' adhesives. Dent Mater 2016; 32: 1218-25. http://dx.doi.org/10.1016/j.dental.2016.07.002.

[26] Spitznagel FA, Vuck A, Gierthmuhlen PC, Blatz MB, Horvath SD. Adhesive bonding to hybrid materials: an overview of materials and recommendations. Compend Contin Educ Dent 2016; 37: 630-7.

[27] Facenda JC, Borba M, Corazza PH. A literature review on the new polymer-infiltrated ceramic-network material (PICN). J Esthet Restor Dent 2018; 30: 281-6. http://dx.doi.org/10.1111/jerd.12370.

[28] Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg 2010; 8: 336-41. http://dx.doi.org/10.1016/j.ijsu.2010.02.007.

[29] Inokoshi M, De Munck J, Minakuchi S, Van Meerbeek B. Meta-analysis of bonding effectiveness to zirconia ceramics. J Dent Res 2014; 93: 329-34. http://dx.doi.org/10.1177/0022034514524228.

[30] Lise DP, Van Ende A, De Munck J, Vieira L, Baratieri LN, Van Meerbeek B. Microtensile bond strength of composite cement to novel CAD/CAM materials as a function of surface treatment and aging. Oper Dent 2017; 42: 73-81. http://dx.doi.org/10.2341/15-263-L.

[31] Isolan CP, Sarkis-Onofre R, Lima GS, Moraes RR. Bonding to sound and caries-affected dentin: a systematic review and meta-analysis. J Adhes Dent 2018; 20: 7-18. http://dx.doi.org/10.3290/j.jad.a39775.

[32] Garcia-Sanz V, Paredes-Gallardo V, Mendoza-Yero O, Carbonell-Leal M, Albaladejo A, Montiel-Company JM, et al. The effects of lasers on bond strength to ceramic materials: A systematic review and meta-analysis. PLoS One 2018; 13: e0190736. http://dx.doi.org/10.1371/journal.pone.0190736.

[33] Frankenberger R, Hartmann VE, Krech M, Kramer N, Reich S, Braun A, et al. Adhesive luting of new CAD/CAM materials. Int J Comput Dent 2015; 18: 9-20.

[34] Campos F, Almeida CS, Rippe MP, de Melo RM, Valandro LF, Bottino MA. Resin bonding to a hybrid ceramic: effects of surface treatments and aging. Oper Dent 2016; 41: 171-8. http://dx.doi.org/10.2341/15-057-L.

[35] Secilmis A, Ustun O, Buyukhatipoglu IK. Evaluation of the shear bond strength of two resin cements on different CAD/CAM materials. J Adhes Sci Technol 2016; 30: 983-93. http://dx.doi.org/10.1080/01694243.2015.1134866.

[36] Hu M, Weiger R, Fischer J. Comparison of two test designs for evaluating the shear bond strength of resin composite cements. Dent Mater 2016; 32: 223-32. http://dx.doi.org/10.1016/j.dental.2015.11.023.

[37] El-Damanhoury HM, Gaintantzopoulou MD. Self-etching ceramic primer versus hydrofluoric acid etching: etching efficacy and bonding performance. J Prosthodont Res 2018; 62: 75-83. http://dx.doi.org/10.1016/j.jpor.2017.06.002.

[38] Kassotakis EM, Stavridakis M, Bortolotto T, Ardu S, Krejci I. Evaluation of the effect of different surface treatments on luting CAD/CAM composite resin overlay workpieces. J Adhes Dent 2015; 17: 521-8. http://dx.doi.org/10.3290/j.jad.a35256.

[39] Duzyol M, Sagsoz O, Polat Sagsoz N, Akgul N, Yildiz M. The effect of surface treatments on the bond strength between CAD/CAM blocks and

composite resin. J Prosthodont 2016; 25: 466-71. http://dx.doi.org/10.1111/jopr.12322.

[40] Kim JE, Kim JH, Shim JS, Roh BD, Shin Y. Effect of air-particle pressures on the surface topography and bond strengths of resin cement to the hybrid ceramics. Dent Mater J 2017; 36: 454-60. http://dx.doi.org/10.4012/dmj.2016-293.

[41] Kim JY, Cho GY, Roh BD, Shin Y. Effect of curing mode on shear bond strength of self-adhesive cement to composite blocks. Materials (Basel) 2016; 9. http://dx.doi.org/10.3390/ma9030210.

[42] 3M Product Instruction for use. 3M. Available at: http://multimedia.3m.com/mws/media/747392O/lava-ultimate-restorative-instructions-for-use-english.pdf. [Accessed 20 December 2018].

[43] VITA Product Instruction for use. VITA ZahnFabrik. Available at: https://cdn.vivarep.com/contrib/vivarep/media/pdf/4_4643_VITAENAMICBondingandPolishingGuide_20170830205802515.pdf. [Accessed 20 December 2018].

[44] GC Product Instruction for use. GC. Available at: http://www.gcamerica.com/products/digital/CERASMART/Statement%20of%20Cerasmart%202015%20PR.pdf. [Accessed 20 December 2018].

[45] Shofu Product Instruction for use. Shofu. Available at: https://www.shofu.de/wp-content/uploads/2017/03/SHOFU-Block-HC-BRO-UK-2017-03.pdf. [Accessed 20 December 2018].

[46] D'Arcangelo C, Vanini L. Effect of three surface treatments on the adhesive properties of indirect composite restorations. J Adhes Dent 2007; 9: 319-26.

[47] Higashi M, Matsumoto M, Kawaguchi A, Miura J, Minamino T, Kabetani T,

et al. Bonding effectiveness of self-adhesive and conventional-type adhesive resin cements to CAD/CAM resin blocks. Part 1: effects of sandblasting and silanization. Dent Mater J 2016; 35: 21-8. http://dx.doi.org/10.4012/dmj.2015-234.

[48] Kurtulmus-Yilmaz S, Cengiz E, Ongun S, Karakaya I. The effect of surface treatments on the mechanical and optical behaviors of CAD/CAM restorative materials. J Prosthodont 2018. http://dx.doi.org/10.1111/jopr.12749.

[49] Matinlinna JP, Lung CYK, Tsoi JKH. Silane adhesion mechanism in dental applications and surface treatments: a review. Dent Mater 2018; 34: 13-28. http://dx.doi.org/10.1016/j.dental.2017.09.002.

[50] Matinlinna JP, Lassila LV, Vallittu PK. The effect of three silane coupling agents and their blends with a cross-linker silane on bonding a bis-GMA resin to silicatized titanium (a novel silane system). J Dent 2006; 34: 740-6. http://dx.doi.org/10.1016/j.jdent.2006.01.008.

[51] Chen C, Chen Y, Lu Z, Qian M, Xie H, Tay FR. The effects of water on degradation of the zirconia-resin bond. J Dent 2017; 64: 23-9. http://dx.doi.org/10.1016/j.jdent.2017.04.004.

[52] Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999; 27: 89-99.

Legends to Figures and Tables

Figures:

Figure 1. Flow diagram of the study selection according to the PRISMA statement.

Figure 2. Forest plot summarizing the bond strengths of the ICs obtained by different surface conditioning methods tested under non-aged conditions.

Figure 3. Forest plot summarizing the bond strengths of the ICs obtained by different surface conditioning methods tested under aged conditions.

Figure 4. Forest plot summarizing the bond strengths of PICN material obtained by different surface conditioning methods tested under non-aged conditions.

Figure 5. Forest plot summarizing the bond strengths of the PICN material obtained by different surface conditioning methods tested under aged conditions.

Figure 6. Forest plot summarizing the bond strengths of the ICDFs obtained by different surface conditioning methods tested under non-aged conditions.

Figure 7. Forest plot summarizing the bond strengths of the ICDFs obtained by different surface conditioning methods tested under aged conditions.

Tables:

Table 1. Characteristics of the included studies.

Table 2. Risk of bias in the studies included in this systematic review.

Figures:

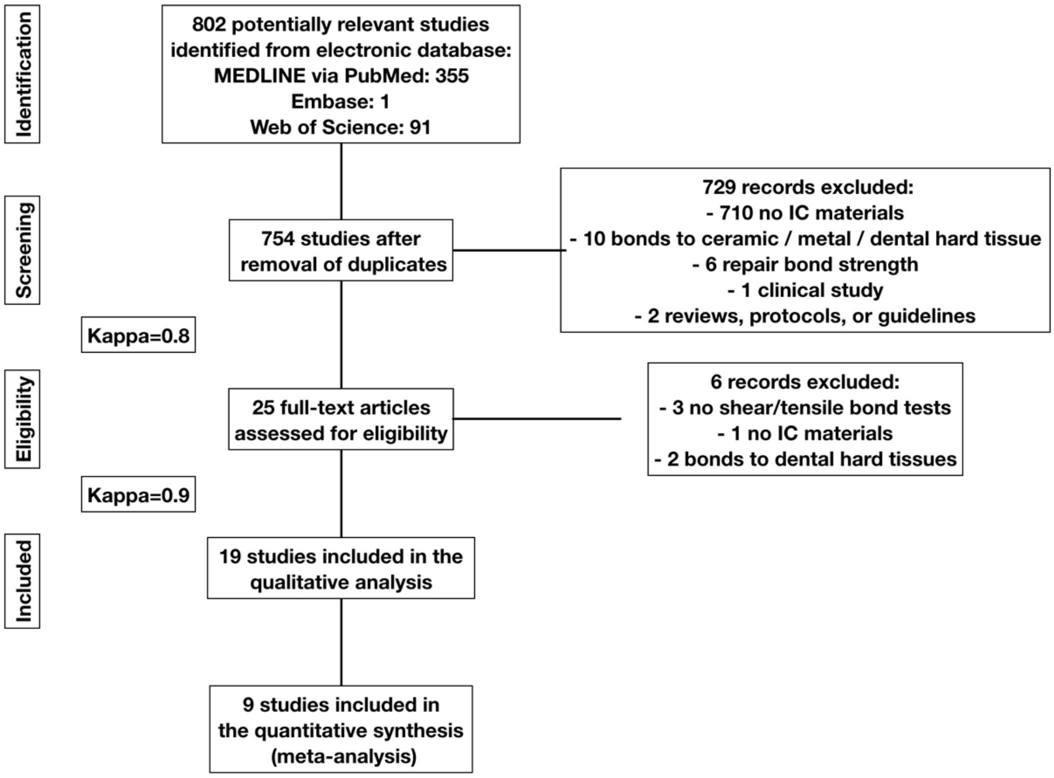

Figure 1. Flow diagram of the study selection according to the PRISMA statement.

Study or Subgroup	conditioned surface Mean	SD	Total	untreated surface Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.10.1 PICN material								
Barutcigil et al. 2016	8.76	3.15	10	7.75	2.34	10	1.0%	1.01 [-1.42, 3.44]
Barutcigil et al. 2016	9.14	2.43	10	7.75	2.34	10	1.0%	1.39 [-0.70, 3.48]
Barutcigil et al. 2016	10.14	2.51	10	7.75	2.34	10	1.0%	2.39 [0.26, 4.52]
Barutcigil et al. 2016	10.73	3.74	10	7.75	2.34	10	1.0%	2.98 [0.25, 5.71]
Barutcigil et al. 2016	9.14	2.64	10	7.75	2.34	10	1.0%	1.39 [-0.80, 3.58]
Campos et al. 2016	47.14	8.1	8	21.96	2.99	8	0.9%	25.18 [19.20, 31.16]
Campos et al. 2016	41.32	13.02	8	21.96	2.99	8	0.8%	19.36 [10.10, 28.62]
Campos et al. 2016	63.25	8.57	8	21.96	2.99	8	0.9%	41.29 [35.00, 47.58]
Elsaka. 2014	18.86	3.31	10	12.67	2.13	10	1.0%	6.19 [3.75, 8.63]
Elsaka. 2014	21.87	3.75	10	18.67	3.1	10	1.0%	3.20 [0.18, 6.22]
Elsaka. 2014	16.71	3.42	10	12.67	2.13	10	1.0%	4.04 [1.54, 6.54]
Elsaka. 2014	23.86	3.19	10	18.67	3.1	10	1.0%	5.19 [2.43, 7.95]
Elsaka. 2014	24.95	3.79	10	18.67	3.1	10	1.0%	6.28 [3.25, 9.31]
Elsaka. 2014	19.48	3.18	10	12.67	2.13	10	1.0%	6.81 [4.44, 9.18]
Elsaka. 2014	27.47	4.28	10	18.67	3.1	10	1.0%	8.80 [5.52, 12.08]
Elsaka. 2014	22.21	3.04	10	12.67	2.13	10	1.0%	9.54 [7.24, 11.84]
Gungor et al. 2016	16.8	1.13	10	14.74	1.13	10	1.1%	2.06 [1.07, 3.05]
Gungor et al. 2016	21.73	0.91	10	14.74	1.13	10	1.1%	6.99 [6.09, 7.89]
Gungor et al. 2016	17.91	1.81	10	14.74	1.13	10	1.1%	3.17 [1.85, 4.49]
Peumans et al. 2016	42.6	4.3	12	17.4	3.2	12	1.0%	25.20 [22.17, 28.23]
Peumans et al. 2016	25.4	4.9	12	17.4	3.2	12	1.0%	8.00 [4.69, 11.31]
Peumans et al. 2016	41.2	5.5	12	17.4	3.2	12	1.0%	23.80 [20.20, 27.40]
Peumans et al. 2016	45.7	4.7	12	17.4	3.2	12	1.0%	28.30 [25.08, 31.52]
Peumans et al. 2016	43.3	5.7	12	17.4	3.2	12	1.0%	25.90 [22.20, 29.60]
Peumans et al. 2016	28.5	3.6	12	18.2	3.8	12	1.0%	10.30 [7.34, 13.26]
Peumans et al. 2016	28.5	3.6	12	18.2	3.8	12	1.0%	10.30 [7.34, 13.26]
Peumans et al. 2016	30.4	4.4	12	18.2	3.8	12	1.0%	12.20 [8.91, 15.49]
Peumans et al. 2016	46.6	5.9	12	18.2	3.8	12	1.0%	28.40 [24.43, 32.37]
Peumans et al. 2016	22.1	4.8	12	17.4	3.2	12	1.0%	4.70 [1.44, 7.96]
Peumans et al. 2016	21.6	4.5	12	17.4	3.2	12	1.0%	4.20 [1.08, 7.32]
Peumans et al. 2016	25.8	5.1	12	17.4	3.2	12	1.0%	8.40 [4.99, 11.81]
Peumans et al. 2016	47.2	4.9	12	17.4	3.2	12	1.0%	29.80 [26.49, 33.11]
Peumans et al. 2016	38.1	5.4	12	18.2	3.8	12	1.0%	19.90 [16.16, 23.64]
Peumans et al. 2016	45.6	5.8	12	18.2	3.8	12	1.0%	27.40 [23.48, 31.32]
Peumans et al. 2016	50.3	6.1	12	18.2	3.8	12	1.0%	32.10 [28.03, 36.17]
Peumans et al. 2016	31.1	5.8	12	18.2	3.8	12	1.0%	12.90 [8.98, 16.82]
Peumans et al. 2016	45.7	6.6	12	18.2	3.8	12	1.0%	27.50 [23.19, 31.81]
Peumans et al. 2016	52.3	5.1	12	18.2	3.8	12	1.0%	34.10 [30.50, 37.70]
Peumans et al. 2016	48.1	5.8	12	18.2	3.8	12	1.0%	29.90 [25.98, 33.82]
Peumans et al. 2016	31.1	4.7	12	17.4	3.2	12	1.0%	13.70 [10.48, 16.92]
Peumans et al. 2016	45.2	5.9	12	17.4	3.2	12	1.0%	27.80 [24.00, 31.60]
Schwenter et al. 2016	8.9	1.3	12	0.5	0.5	12	1.1%	8.40 [7.61, 9.19]
Schwenter et al. 2016	10.2	2.8	12	0.5	0.5	12	1.1%	9.70 [8.09, 11.31]
Schwenter et al. 2016	17.3	2.5	12	0.5	0.5	12	1.1%	16.80 [15.36, 18.24]
Schwenter et al. 2016	19.7	2.1	12	0.5	0.5	12	1.1%	19.20 [17.98, 20.42]
Schwenter et al. 2016	18.4	3.1	12	0.5	0.5	12	1.1%	17.90 [16.12, 19.68]
Schwenter et al. 2016	16.5	2.5	12	0.5	0.5	12	1.1%	16.00 [14.56, 17.44]
Schwenter et al. 2016	14.5	2.9	12	0.5	0.5	12	1.1%	14.00 [12.33, 15.67]
Schwenter et al. 2016	10.2	2.7	12	0.5	0.5	12	1.1%	9.70 [8.15, 11.25]
Schwenter et al. 2016	11.8	1.8	12	0.5	0.5	12	1.1%	11.30 [10.24, 12.36]
Schwenter et al. 2016	12.7	1.8	12	0.5	0.5	12	1.1%	12.20 [11.14, 13.26]
Schwenter et al. 2016	12.3	2.4	12	0.5	0.5	12	1.1%	11.80 [10.41, 13.19]
Schwenter et al. 2016	11.3	2.1	12	0.5	0.5	12	1.1%	10.80 [9.58, 12.02]
Subtotal (95% CI)			**592**			**592**	**54.4%**	**14.07 [12.17, 15.97]**
Heterogeneity: $Tau^2 = 47.50$; $Chi^2 = 2578.34$, df = 52 ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 14.48$ ($P < 0.00001$)								
1.10.2 ICs with dispersed fillers								
Arao et al. 2015	36.1	2.5	7	25.6	2.9	7	1.0%	10.50 [7.66, 13.34]
Arao et al. 2015	23.9	2.5	7	25.6	2.9	7	1.0%	-1.70 [-4.54, 1.14]
Arao et al. 2015	28.4	3.2	7	25.6	2.9	7	1.0%	2.80 [-0.40, 6.00]
Arao et al. 2015	29.8	3	7	11.3	1.7	7	1.0%	18.50 [15.95, 21.05]
Arao et al. 2015	40.3	1.4	7	11.3	1.7	7	1.1%	29.00 [27.37, 30.63]
Arao et al. 2015	19.6	2	7	11.3	1.7	7	1.0%	8.30 [6.36, 10.24]
Elsaka. 2014	18.82	3.69	10	11.99	2.52	10	1.0%	6.83 [4.06, 9.60]
Elsaka. 2014	13.88	3.47	10	8.28	1.99	10	1.0%	5.60 [3.12, 8.08]
Elsaka. 2014	19.21	3.87	10	11.99	2.52	10	1.0%	7.22 [4.36, 10.08]
Elsaka. 2014	14.35	2.56	10	8.28	1.99	10	1.0%	6.07 [4.06, 8.08]
Elsaka. 2014	16.93	3.66	10	11.99	2.52	10	1.0%	4.94 [2.19, 7.69]
Elsaka. 2014	13.49	3.4	10	8.28	1.99	10	1.0%	5.21 [2.77, 7.65]
Elsaka. 2014	18.35	2.84	10	11.99	2.52	10	1.0%	6.36 [4.01, 8.71]
Elsaka. 2014	13.45	3.24	10	8.28	1.99	10	1.0%	5.17 [2.81, 7.53]
Gungor et al. 2016	14.29	1.21	10	13.64	1.24	10	1.1%	0.65 [-0.42, 1.72]
Gungor et al. 2016	20.64	1.38	10	13.64	1.24	10	1.1%	7.00 [5.85, 8.15]
Gungor et al. 2016	16.08	1.13	10	13.64	1.24	10	1.1%	2.44 [1.40, 3.48]
Gungor et al. 2016	15.59	1.59	10	5.35	0.53	9	1.1%	10.24 [9.20, 11.28]
Gungor et al. 2016	16.09	1.14	10	5.35	0.53	9	1.1%	10.74 [9.95, 11.53]
Gungor et al. 2016	16.28	1.12	10	5.35	0.53	9	1.1%	10.93 [10.15, 11.71]
Peumans et al. 2016	50.2	5.4	12	3.1	6.5	3	0.9%	47.10 [39.14, 55.06]
Peumans et al. 2016	52.3	5.9	12	3.1	6.5	3	0.8%	49.20 [41.12, 57.28]
Peumans et al. 2016	57.5	4.7	12	3.1	6.5	3	0.9%	54.40 [46.58, 62.22]
Peumans et al. 2016	40.1	8.7	12	3.1	6.5	3	0.8%	37.00 [28.15, 45.85]
Peumans et al. 2016	56.5	5.9	12	10.4	6.9	10	1.0%	46.10 [40.67, 51.53]
Peumans et al. 2016	54.2	6.7	12	10.4	6.9	10	0.9%	43.80 [38.09, 49.51]
Peumans et al. 2016	56.4	5.5	12	10.4	6.9	10	1.0%	46.00 [40.71, 51.29]
Peumans et al. 2016	43.8	4.1	12	10.4	6.9	10	1.0%	33.40 [28.53, 38.27]
Peumans et al. 2016	40.7	3.7	12	10.4	6.9	10	1.0%	30.30 [25.54, 35.06]
Peumans et al. 2016	42.2	4.4	12	10.4	6.9	10	1.0%	31.80 [26.85, 36.75]
Peumans et al. 2016	42.2	5.1	12	10.4	6.9	10	1.0%	31.80 [26.64, 36.96]
Peumans et al. 2016	49.1	4.3	12	3.1	6.5	12	1.0%	46.00 [41.59, 50.41]
Peumans et al. 2016	34.6	4.4	12	3.1	6.5	12	1.0%	31.50 [27.06, 35.94]
Peumans et al. 2016	58.2	3.6	12	10.4	6.9	12	1.0%	47.80 [43.40, 52.20]
Peumans et al. 2016	38.4	5.2	12	10.4	6.9	12	1.0%	28.00 [23.11, 32.89]
Peumans et al. 2016	47.1	4.3	12	10.4	6.9	12	1.0%	36.70 [32.10, 41.30]
Peumans et al. 2016	33.3	4.6	12	10.4	6.9	12	1.0%	22.90 [18.21, 27.59]
Peumans et al. 2016	28.1	5.2	12	3.1	6.5	12	1.0%	25.00 [20.29, 29.71]
Peumans et al. 2016	38.9	3.9	12	3.1	6.5	12	1.0%	35.80 [31.51, 40.09]
Peumans et al. 2016	50.1	5.8	12	3.1	6.5	3	0.8%	47.00 [38.95, 55.05]
Peumans et al. 2016	39.9	6.1	12	3.1	6.5	3	0.8%	36.80 [28.68, 44.92]
Peumans et al. 2016	55.1	4.2	12	3.1	6.5	3	0.9%	52.00 [44.27, 59.73]
Schwenter et al. 2016	16.93	3.66	10	11.99	2.52	10	1.0%	4.94 [2.19, 7.69]
Schwenter et al. 2016	13.49	3.4	10	8.28	1.99	10	1.0%	5.21 [2.77, 7.65]
Schwenter et al. 2016	18.35	2.84	10	16.93	3.66	10	1.0%	1.42 [-1.45, 4.29]
Schwenter et al. 2016	13.45	3.24	10	8.28	1.99	10	1.0%	5.17 [2.81, 7.53]
Subtotal (95% CI)			**486**			**406**	**45.6%**	**21.77 [18.83, 24.71]**
Heterogeneity: $Tau^2 = 98.38$; $Chi^2 = 3715.35$, df = 45 ($P < 0.00001$); $I^2 = 99\%$								
Test for overall effect: $Z = 14.52$ ($P < 0.00001$)								
Total (95% CI)			**1078**			**998**	**100.0%**	**17.48 [15.84, 19.13]**
Heterogeneity: $Tau^2 = 66.29$; $Chi^2 = 6295.12$, df = 98 ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 20.80$ ($P < 0.00001$)								
Test for subgroup differences: $Chi^2 = 18.58$, df = 1 ($P < 0.0001$), $I^2 = 94.6\%$								

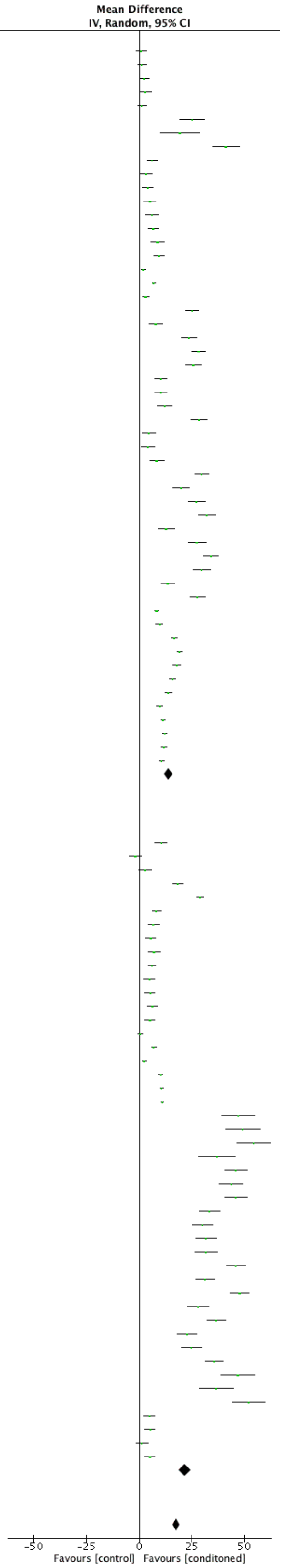

Figure 2. Forest plot summarizing the bond strengths of the ICs obtained by different surface conditioning methods tested under non-aged conditions.

Study or Subgroup	conditioned surface Mean	SD	Total	untreated surface Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.9.1 PICN material								
El-Damanhourya and Gaintantzopoulou, 2018	21.33	6.78	10	3.43	4.06	10	2.6%	17.90 [13.00, 22.80]
El-Damanhourya and Gaintantzopoulou, 2018	14.69	6.78	10	3.43	4.06	10	2.6%	11.26 [6.36, 16.16]
El-Damanhourya and Gaintantzopoulou, 2018	25.96	11.58	10	3.43	4.06	10	2.0%	22.53 [14.92, 30.14]
Frankenberger et al. 2015	16.7	3.1	100	8.4	3	100	3.3%	8.30 [7.45, 9.15]
Frankenberger et al. 2015	9.1	2.7	100	8.4	3	100	3.3%	0.70 [−0.09, 1.49]
Frankenberger et al. 2015	12.7	2.9	100	8.4	3	100	3.3%	4.30 [3.48, 5.12]
Frankenberger et al. 2015	13	3.5	100	8.4	3	100	3.3%	4.60 [3.70, 5.50]
Gungor et al. 2016	22.16	1.86	10	15.01	1.22	10	3.2%	7.15 [5.77, 8.53]
Gungor et al. 2016	13.95	0.89	10	15.01	1.22	10	3.3%	−1.06 [−2.00, −0.12]
Gungor et al. 2016	17.41	1.41	10	15.01	1.22	10	3.2%	2.40 [1.24, 3.56]
Subtotal (95% CI)			**460**			**460**	**29.9%**	**6.47 [4.04, 8.91]**
Heterogeneity: $Tau^2 = 13.41$; $Chi^2 = 368.05$, df = 9 ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 5.22$ ($P < 0.00001$)								
1.9.2 ICs with dispersed fillers								
Arao et al. 2015	23.4	2.1	7	13.9	1.6	7	3.2%	9.50 [7.54, 11.46]
Arao et al. 2015	32.7	4.4	7	13.9	1.6	7	2.9%	18.80 [15.33, 22.27]
Arao et al. 2015	30	2	7	13.9	1.6	7	3.2%	16.10 [14.20, 18.00]
Arao et al. 2015	11.4	1.7	7	8.1	2.3	7	3.1%	3.30 [1.18, 5.42]
Arao et al. 2015	27.5	3.1	7	8.1	2.3	7	3.0%	19.40 [16.54, 22.26]
Arao et al. 2015	35.1	2.8	7	8.1	2.3	7	3.0%	27.00 [24.32, 29.68]
Frankenberger et al. 2015	16.1	4.5	100	9.5	3.7	100	3.2%	6.60 [5.46, 7.74]
Frankenberger et al. 2015	10.4	6.9	100	4.5	6.7	100	3.2%	5.90 [4.01, 7.79]
Frankenberger et al. 2015	10.4	3.5	100	9.5	3.7	100	3.3%	0.90 [−0.10, 1.90]
Frankenberger et al. 2015	10.2	3.1	100	9.5	3.7	100	3.3%	0.70 [−0.25, 1.65]
Frankenberger et al. 2015	15.7	3.2	100	9.5	3.7	100	3.3%	6.20 [5.24, 7.16]
Frankenberger et al. 2015	9.1	3.1	100	9.5	3.7	100	3.3%	−0.40 [−1.35, 0.55]
Frankenberger et al. 2015	16.8	4.6	100	4.5	6.7	100	3.2%	12.30 [10.71, 13.89]
Frankenberger et al. 2015	4.2	9.1	100	4.5	6.7	100	3.1%	−0.30 [−2.51, 1.91]
Frankenberger et al. 2015	11.2	5.5	100	4.5	6.7	100	3.2%	6.70 [5.00, 8.40]
Frankenberger et al. 2015	17.9	4.5	100	4.5	6.7	100	3.2%	13.40 [11.82, 14.98]
Gungor et al. 2016	15	1.13	10	11.02	1.04	10	3.3%	3.98 [3.03, 4.93]
Gungor et al. 2016	17.25	1.54	10	11.02	1.04	10	3.2%	6.23 [5.08, 7.38]
Gungor et al. 2016	16.31	1.58	10	11.02	1.04	10	3.2%	5.29 [4.12, 6.46]
Gungor et al. 2016	15.79	0.95	10	5.4	0.85	6	3.3%	10.39 [9.49, 11.29]
Gungor et al. 2016	15.49	1.22	10	5.4	0.85	6	3.3%	10.09 [9.07, 11.11]
Gungor et al. 2016	16.34	1.15	9	5.4	0.85	6	3.3%	10.94 [9.93, 11.95]
Subtotal (95% CI)			**1101**			**1090**	**70.1%**	**8.66 [6.48, 10.85]**
Heterogeneity: $Tau^2 = 26.63$; $Chi^2 = 1321.98$, df = 21 ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 7.76$ ($P < 0.00001$)								
Total (95% CI)			**1561**			**1550**	**100.0%**	**8.11 [6.42, 9.81]**
Heterogeneity: $Tau^2 = 22.69$; $Chi^2 = 1844.06$, df = 31 ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 9.39$ ($P < 0.00001$)								
Test for subgroup differences: $Chi^2 = 1.72$, df = 1 ($P = 0.19$), $I^2 = 41.9\%$								

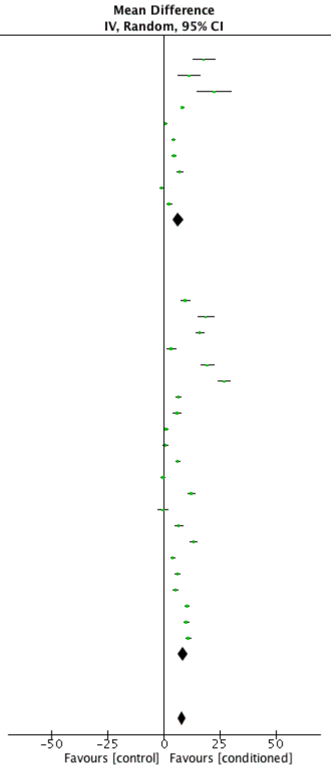

Figure 3. Forest plot summarizing the bond strengths of the ICs obtained by different surface conditioning methods tested under aged conditions.

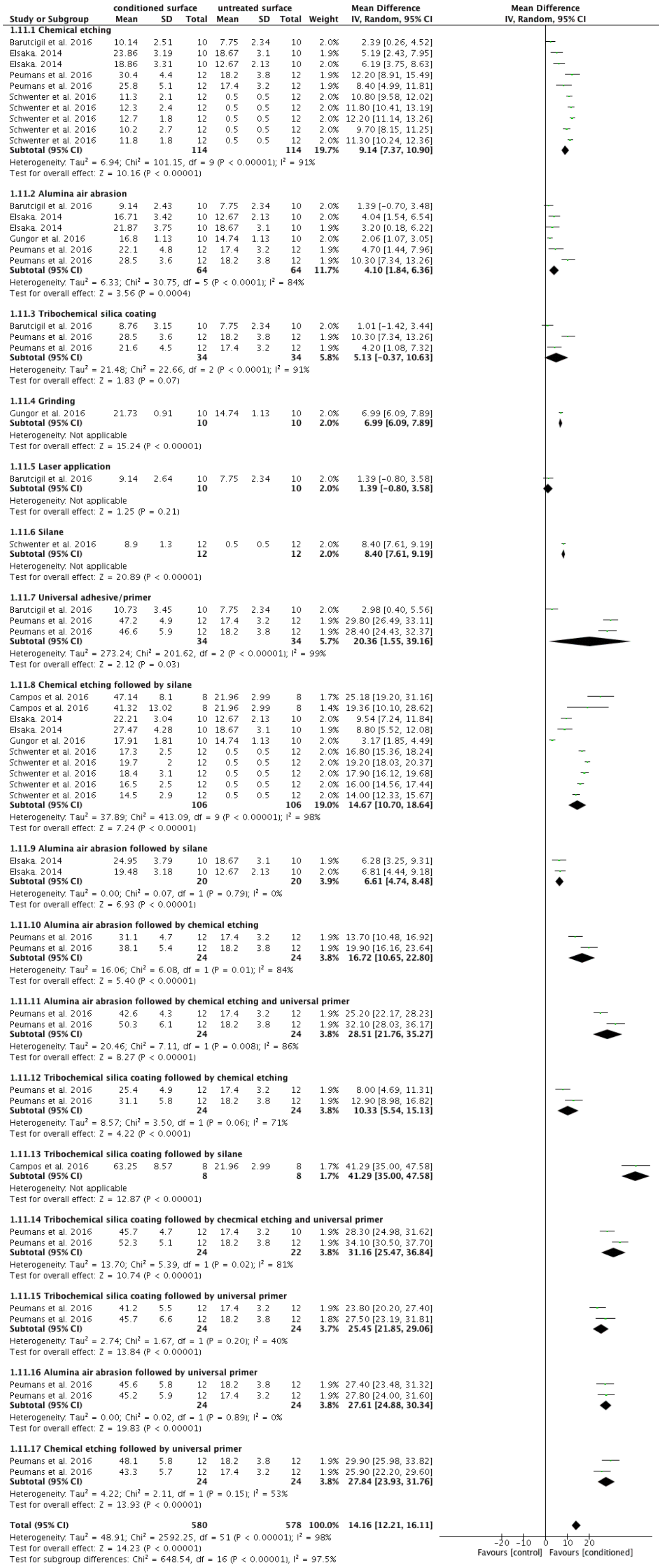

Figure 4. Forest plot summarizing the bond strengths of PICN material obtained by different surface conditioning methods tested under non-aged conditions.

Study or Subgroup	conditioned surface Mean	SD	Total	untreated surface Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
1.12.1 chemical etching								
Frankenberger et al. 2015	16.1	4.7	100	8.4	3	100	9.9%	7.70 [6.61, 8.79]
Subtotal (95% CI)			**100**			**100**	**9.9%**	**7.70 [6.61, 8.79]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 13.81 (P < 0.00001)								
1.12.2 alumina air abrasion								
Frankenberger et al. 2015	12.7	2.9	100	8.4	3	100	17.6%	4.30 [3.48, 5.12]
Gungor et al. 2016	13.95	0.89	10	15.01	1.22	10	13.5%	−1.06 [−2.00, −0.12]
Subtotal (95% CI)			**110**			**110**	**31.1%**	**1.98 [1.36, 2.60]**
Heterogeneity: Chi^2 = 71.44, df = 1 (P < 0.00001); I^2 = 99%								
Test for overall effect: Z = 6.30 (P < 0.00001)								
1.12.3 Grinding								
Gungor et al. 2016	17.41	1.41	10	15.01	1.22	10	8.8%	2.40 [1.24, 3.56]
Subtotal (95% CI)			**10**			**10**	**8.8%**	**2.40 [1.24, 3.56]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 4.07 (P < 0.0001)								
1.12.4 universal primer								
El-Damanhourya and Gaintantzopoulou, 2018	14.69	6.78	10	3.43	4.06	10	0.5%	11.26 [6.36, 16.16]
Frankenberger et al. 2015	9.1	2.7	100	8.4	3	100	18.8%	0.70 [−0.09, 1.49]
Subtotal (95% CI)			**110**			**110**	**19.3%**	**0.97 [0.19, 1.75]**
Heterogeneity: Chi^2 = 17.40, df = 1 (P < 0.0001); I^2 = 94%								
Test for overall effect: Z = 2.43 (P = 0.02)								
1.12.5 Chemical etching followed by universal primer								
El-Damanhourya and Gaintantzopoulou, 2018	21.33	5.03	10	3.43	4.06	12	0.8%	17.90 [14.03, 21.77]
Frankenberger et al. 2015	20.2	4.9	100	8.4	3	100	9.3%	11.80 [10.67, 12.93]
Subtotal (95% CI)			**110**			**112**	**10.1%**	**12.28 [11.19, 13.36]**
Heterogeneity: Chi^2 = 8.79, df = 1 (P = 0.003); I^2 = 89%								
Test for overall effect: Z = 22.25 (P < 0.00001)								
1.12.6 Alumina air abrasion followed by universal primer								
Frankenberger et al. 2015	13	3.5	100	8.4	3	100	14.4%	4.60 [3.70, 5.50]
Subtotal (95% CI)			**100**			**100**	**14.4%**	**4.60 [3.70, 5.50]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 9.98 (P < 0.00001)								
1.12.7 Chemical etching followed by silane								
El-Damanhourya and Gaintantzopoulou, 2018	25.96	11.58	10	3.43	4.06	10	0.2%	22.53 [14.92, 30.14]
Gungor et al. 2016	22.16	1.86	10	15.01	1.22	10	6.2%	7.15 [5.77, 8.53]
Subtotal (95% CI)			**20**			**20**	**6.4%**	**7.64 [6.28, 9.00]**
Heterogeneity: Chi^2 = 15.21, df = 1 (P < 0.0001); I^2 = 93%								
Test for overall effect: Z = 11.04 (P < 0.00001)								
Total (95% CI)			**560**			**562**	**100.0%**	**4.16 [3.82, 4.51]**
Heterogeneity: Chi^2 = 516.95, df = 10 (P < 0.00001); I^2 = 98%								
Test for overall effect: Z = 23.78 (P < 0.00001)								
Test for subgroup differences: Chi^2 = 404.11, df = 6 (P < 0.00001), I^2 = 98.5%								

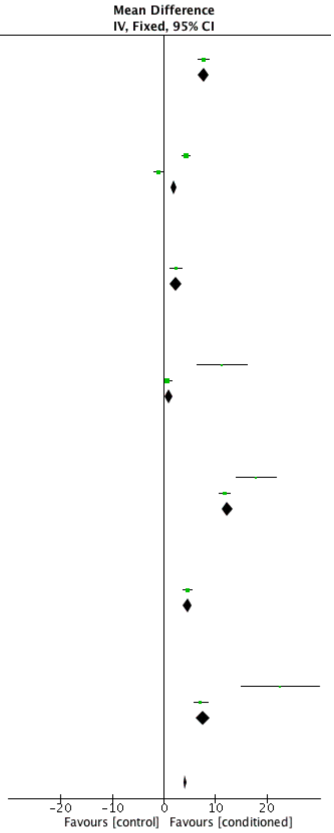

Figure 5. Forest plot summarizing the bond strengths of the PICN material obtained by different surface conditioning methods tested under aged conditions.

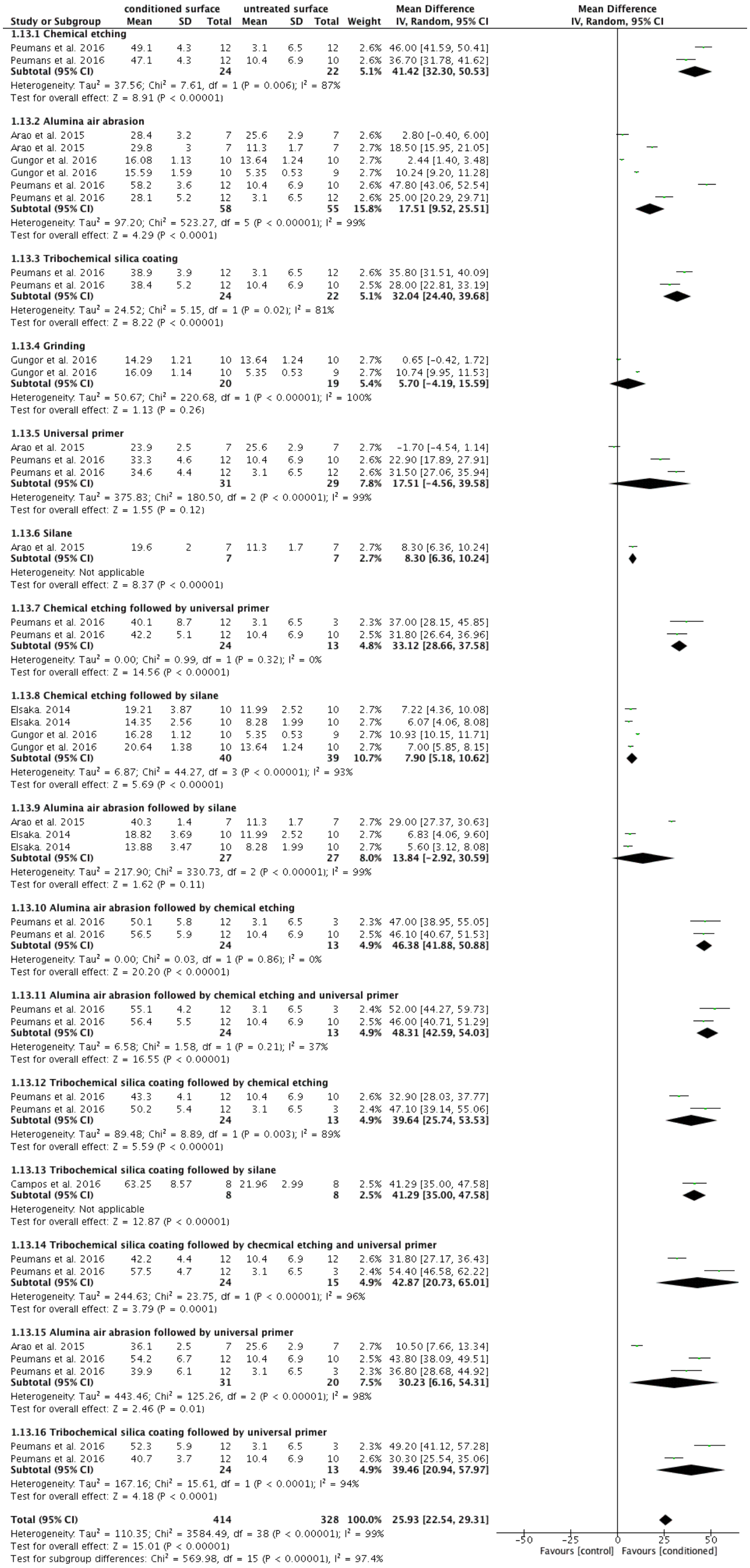

Figure 6. Forest plot summarizing the bond strengths of the ICDFs obtained by different surface conditioning methods tested under non-aged conditions.

Study or Subgroup	conditioned surface Mean	SD	Total	untreated surface Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.14.1 chemical etching								
Frankenberger et al. 2015	10.4	6.9	100	4.5	6.7	100	4.5%	5.90 [4.01, 7.79]
Frankenberger et al. 2015	9.1	3.1	100	9.5	3.7	100	4.6%	-0.40 [-1.35, 0.55]
Subtotal (95% CI)			**200**			**200**	**9.2%**	**2.70 [-3.48, 8.87]**
Heterogeneity: $Tau^2 = 19.27$; $Chi^2 = 34.27$, $df = 1$ ($P < 0.00001$); $I^2 = 97\%$								
Test for overall effect: $Z = 0.86$ ($P = 0.39$)								
1.14.2 alumina air abrasion								
Arao et al. 2015	30	2	7	13.9	1.6	7	4.5%	16.10 [14.20, 18.00]
Arao et al. 2015	27.5	3.1	7	8.1	2.3	7	4.3%	19.40 [16.54, 22.26]
Frankenberger et al. 2015	17.9	4.5	100	4.5	6.7	100	4.6%	13.40 [11.82, 14.98]
Frankenberger et al. 2015	15.7	3.2	100	9.5	3.7	100	4.6%	6.20 [5.24, 7.16]
Gungor et al. 2016	15	1.13	10	11.02	1.04	10	4.6%	3.98 [3.03, 4.93]
Gungor et al. 2016	15.79	0.95	10	5.4	0.85	6	4.6%	10.39 [9.49, 11.29]
Subtotal (95% CI)			**234**			**230**	**27.3%**	**11.45 [7.62, 15.27]**
Heterogeneity: $Tau^2 = 22.10$; $Chi^2 = 279.94$, $df = 5$ ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 5.87$ ($P < 0.00001$)								
1.14.3 Grinding								
Gungor et al. 2016	15.49	1.22	10	5.4	0.85	6	4.6%	10.09 [9.07, 11.11]
Gungor et al. 2016	17.25	1.54	10	11.02	1.04	10	4.6%	6.23 [5.08, 7.38]
Subtotal (95% CI)			**20**			**16**	**9.2%**	**8.17 [4.39, 11.95]**
Heterogeneity: $Tau^2 = 7.14$; $Chi^2 = 24.24$, $df = 1$ ($P < 0.00001$); $I^2 = 96\%$								
Test for overall effect: $Z = 4.23$ ($P < 0.0001$)								
1.14.4 silane								
Arao et al. 2015	11.4	1.7	7	8.1	2.3	7	4.5%	3.30 [1.18, 5.42]
Subtotal (95% CI)			**7**			**7**	**4.5%**	**3.30 [1.18, 5.42]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 3.05$ ($P = 0.002$)								
1.14.5 Universal primer								
Arao et al. 2015	23.4	2.1	7	13.9	1.6	7	4.5%	9.50 [7.54, 11.46]
Frankenberger et al. 2015	10.2	3.1	100	9.5	3.7	100	4.6%	0.70 [-0.25, 1.65]
Frankenberger et al. 2015	4.2	9.1	100	4.5	6.7	100	4.5%	-0.30 [-2.51, 1.91]
Subtotal (95% CI)			**207**			**207**	**13.6%**	**3.29 [-2.32, 8.89]**
Heterogeneity: $Tau^2 = 23.68$; $Chi^2 = 67.88$, $df = 2$ ($P < 0.00001$); $I^2 = 97\%$								
Test for overall effect: $Z = 1.15$ ($P = 0.25$)								
1.14.6 Alumina air abrasion followed by silane								
Arao et al. 2015	35.1	2.8	7	8.1	2.3	7	4.4%	27.00 [24.32, 29.68]
Subtotal (95% CI)			**7**			**7**	**4.4%**	**27.00 [24.32, 29.68]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 19.71$ ($P < 0.00001$)								
1.14.7 Chemical etching followed by silane								
Gungor et al. 2016	16.31	1.58	10	11.02	1.04	10	4.6%	5.29 [4.12, 6.46]
Gungor et al. 2016	16.34	1.15	9	5.4	0.85	6	4.6%	10.94 [9.93, 11.95]
Subtotal (95% CI)			**19**			**16**	**9.2%**	**8.12 [2.59, 13.66]**
Heterogeneity: $Tau^2 = 15.65$; $Chi^2 = 51.06$, $df = 1$ ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 2.88$ ($P = 0.004$)								
1.14.8 Alumina air abrasion followed by universal primer								
Arao et al. 2015	32.7	4.4	7	13.9	1.6	7	4.2%	18.80 [15.33, 22.27]
Frankenberger et al. 2015	16.1	4.5	100	9.5	3.7	100	4.6%	6.60 [5.46, 7.74]
Frankenberger et al. 2015	16.8	4.6	100	4.5	6.7	100	4.6%	12.30 [10.71, 13.89]
Subtotal (95% CI)			**207**			**207**	**13.4%**	**12.35 [6.53, 18.17]**
Heterogeneity: $Tau^2 = 25.13$; $Chi^2 = 63.90$, $df = 2$ ($P < 0.00001$); $I^2 = 97\%$								
Test for overall effect: $Z = 4.16$ ($P < 0.0001$)								
1.14.9 Chemical etching followed by universal primer								
Frankenberger et al. 2015	11.2	5.5	100	4.5	6.7	100	4.5%	6.70 [5.00, 8.40]
Frankenberger et al. 2015	10.4	3.5	100	9.5	3.7	100	4.6%	0.90 [-0.10, 1.90]
Subtotal (95% CI)			**200**			**200**	**9.2%**	**3.76 [-1.93, 9.44]**
Heterogeneity: $Tau^2 = 16.31$; $Chi^2 = 33.28$, $df = 1$ ($P < 0.00001$); $I^2 = 97\%$								
Test for overall effect: $Z = 1.30$ ($P = 0.20$)								
Total (95% CI)			**1101**			**1090**	**100.0%**	**8.66 [6.48, 10.85]**
Heterogeneity: $Tau^2 = 26.63$; $Chi^2 = 1321.98$, $df = 21$ ($P < 0.00001$); $I^2 = 98\%$								
Test for overall effect: $Z = 7.76$ ($P < 0.00001$)								
Test for subgroup differences: $Chi^2 = 210.18$, $df = 8$ ($P < 0.00001$), $I^2 = 96.2\%$								

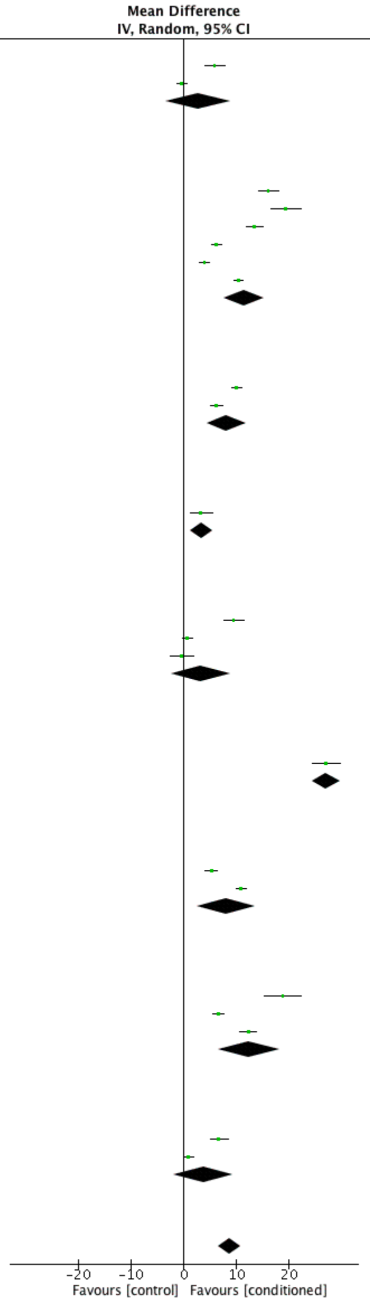

Figure 7. Forest plot summarizing the bond strengths of the ICDFs obtained by different surface conditioning methods tested under aged conditions.

Author/publication year	ICs tested	Surface conditioning methods	Luting materials	Specimen number per group	Bonding antagonist	Artificial aging methods	Bond strength test
Elsaka 2014	Vita Enamic/Lava Ultimate Restorative	Alumina air abrasion/alumina air abrasion + silane/HF etch/HF etch + silane	Bifix SE	20	Filtek Z250	1 d in 37ºC water	Micro-tensile
Kassotakis et al. 2015	Lava Ultimate Restorative	$NaHCO_3$ powder air abrasion/glycine powder air abrasion/alumina air abrasion/tribochemical silica coating	Single Bond Universal + Filtek Ultimate	30	Similar conditioned IC	2 week in 37ºC water/3,000 thermocycles	Micro-tensile
Frankenberger et al. 2015	Vita Enamic/ Lava Ultimate Restorative	Silane/alumina air abrasion/alumina air abrasion + universal primer/HF etch/HF etch+ universal primer	Prime&Bond XP + Self-Cure Activator + Calibra Esthetic/RelyX Unicem	100	Similar resin cement	2 d in 37ºC water/10,000 thermocycles	Micro-tensile
Arao et al. 2015	GC Cerasmart/ Shofu Block HC	Alumina air abrasion /glass beads air abrasion/alumina air abrasion + silane /glass beads air abrasion + silane	Unifil Core EM	7	Similar resin cement	1 d in 37ºC water/10,000 thermocycles	Shear

Campos et al. 2016	Vita Enamic	Phosphoric acid etch + silane/HF etch + silane/tribochemical silica coating + silane	Panavia F	12	Z350XT	6000 thermocycles + 60 d in 37ºC water	Micro-tensile
Lise et al. 2016	Vita Enamic/GC Cerasmart	Alumina air abrasion/alumina air abrasion + silane/HF etch + silane/phosphoric acid etch + silane	G-CEM LinkAce/Genial Universal Flo	>13	Similar conditioned IC	3 weeks / 6 months in 37ºC 0.5% chloramine	Micro-tensile
Schwenter et al. 2016	Vita Enamic	Polish + HF etch/polish + HF etch + silane	RelyX Unicem 2/Clearfil SA/Variolink II	12	Similar resin cement	1 d in 37ºC water	Shear
Yoshihara et al. 2016	Lava Ultimate Restorative	Universal adhesive/ universal adhesive + silane/silane-free universal adhesive/ silane-free universal + silane	Clearfil Esthetic Cement	20	Similar conditioned IC	1 d in 37ºC water/15,000 thermocycles	Shear
Secilmis et al. 2016	Vita Enamic/ Lava Ultimate Restorative	Alumina air abrasion + HF etch + silane	SE Bond + Panavia 2.0/Multilink N	24	Similar resin cement	1 d in 37ºC water/15,000 thermocycles	Shear
Nagas-Cekic et al. 2016	Vita Enamic/ Lava Ultimate Restorative /GC Cerasmart	Grinding/HF etch	RelyX Ultimate + Scotchbond Universal/ Variolink Esthetic DC + Monobond Plus/G-CEM LinkAce + GC Ceramic Primer	16	Similar resin cement	2 d in 37ºC water/5,000 thermocycles	Micro-shear

Duzyol et al. 2016	Lava Ultimate Restorative	Grinding + silane/grinding + HF etch + silane/grinding + alumina air abrasion + silane/grinding + tribochemical silica coating + silane	Single Bond Universal	40	Filtek Z550	1 week in 37ºC water	Micro-tensile
Kim et al. 2016	Lava Ultimate Restorative	Grinding + alumina air abrasion	Single Bond Universal + RelyX ultimate/RelyX U200/G-cem cerasmart	18	Similar resin cement	1 d in 25ºC water	Micro-shear
Peumans et al. 2016	Vita Enamic/ Lava Ultimate Restorative	HF etch/universal primer/HF etch + universal primer	Heliobond + Clearfil Esthetic Cement/Panavia SA Cement	18	Similar ceramic/polymer material	7 d in 37ºC water	Micro-tensile
Barutcigil et al. 2016	Vita Enamic	Tribochemical silica coating/alumina air abrasion/HF etch/Universal adhesive/Er,Cr:YSGG laser	RelyX U200	10	Similar resin cement	1 d storage in 37ºC water	Shear
Hu et al. 2016	Vita Enamic	Polish + silane/grind + HF etch + silane	RelyX Unicem 2/Maxcem Elite/PermaFlo DC	10	Similar resin cement	1 d storage in 37ºC water	Shear
Gungor et al. 2016	Vita Enamic/ Lava Ultimate Restorative /GC Cerasmart	Alumina air abrasion/grinding/HF etch + silane	Clearfil Majesty Esthetic	10	Similar composite resin	1 d in 37ºC water/10,000 thermocycles	Shear

Rohr et al. 2017	Vita Enamic	Polish/polish + silane/polish + universal adhesive/polish + silane + universal adhesive/HF etch + silane/HF etch + universal adhesive/HF etch + silane + universal adhesive	RelyX Ultimate/RelyX Unicem 2	10	Similar resin cement	1 d in 37ºC water	Shear
Kim et al. 2017	Lava Ultimate Restorative /Mazic DUO	Alumina air abrasion	Single Bond Universal +RelyX U200	15	Similar resin cement	1 d storage in 37ºC water	Shear
El-Damanhourya and Gaintantzopoulou 2018	Vita Enamic	Silane/HF etch + silane/self-etch silane	Multilink-N Automix	10	Similar resin cement	1 d in 37ºC water + 5,000 thermocycles	Shear

Table 1. Characteristics of the included studies.

Author/ year of publication	Randomization	Sample size calculation	Adequate control	Conditioning protocol	Material handling	Statistical analysis	Failure mode analysis	Blinded operator	Risk of bias
Elsaka. 2014	N	N	Y	Y	Y	Y	Y	N	Medium
Kassotakis et al. 2015	Y	N	N	Y	Y	Y	Y	N	Low
Lise et al. 2015	Y	N	N	Y	Y	Y	Y	N	Low
Frankenberger et al. 2015	Y	N	Y	Y	Y	Y	N	N	Medium
Arao et al. 2015	N	N	Y	Y	Y	Y	Y	N	Medium
Campos et al. 2016	N	N	N	Y	Y	Y	Y	N	Medium
Schwenter et al. 2016	N	N	Y	Y	Y	Y	Y	N	Medium
Yoshihara et al. 2016	N	N	N	Y	Y	Y	Y	N	Medium
Secilmis et al. 2016	Y	N	N	N	Y	Y	N	N	High
Nagas-Cekic et al. 2016	Y	N	N	Y	Y	Y	Y	N	Medium
Duzyol et al. 2016	N	N	N	Y	Y	Y	N	N	High
Kim et al. 2016	N	N	N	Y	Y	Y	Y	N	Medium
Peumans et al. 2016	Y	N	Y	Y	Y	Y	Y	N	Low
Barutcigil et al. 2016	Y	N	Y	Y	Y	Y	Y	N	Low
Hu et al. 2016	N	N	N	Y	Y	Y	Y	N	Medium
Gungior et al. 2016	N	N	Y	Y	Y	Y	N	N	Medium
Rohr et al. 2017	N	N	Y	Y	Y	Y	N	N	Medium
Kim et al. 2017	Y	N	N	Y	Y	Y	Y	N	Medium
El-Damanhourya and Gaintantzopoulou. 2018	Y	N	Y	Y	Y	Y	Y	N	Low

Table 2. Risk of bias in the studies included in this systematic review.